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Experimental Critical Heat Flux for APR1400 Low Head During a Severe Accident

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1. Introduction

The in-vessel retention (IVR) is a key severe accident management strategy adopted by several operating nuclear power plants, and proposed for the advanced light water reactors. External reactor vessel cooling (ERVC) by reactor cavity flooding is one of the key severe accident management strategies for IVR. The Advanced Power Reactor 1400 MWe (APR1400) has adopted the IVR-ERVC strategy. The ERVC system in the severe accident management design depends upon the active flooding with a specific thermal insulation structure using natural circulation [1-7].

Experimental studies are available for IVR-ERVC. Two-dimensional (2D) test sections were used at both the ULPU facility of the University of California Santa Barbara [5] and the critical heat flux (CHF) facility of the Korea Advanced Institute of Science and Technology [6]. The SBLB facility of the Pennsylvania State University had the CHF data taken from a three-dimensional (3D) test section whose heated block was of 2D slice, though [7]. Most recently, the Corium Ablation Stopper Apparatus (CASA) tests were conducted at the Seoul National University to measure the CHF on a downward 3D hemispherical vessel.

2. Experimental Work

The CASA tests were run to measure the CHF and critical power and on a downward hemispherical vessel scaled linearly down from the APR1400 lower head by 1/10. CASA was designed through scaling analysis to simulate the thermal insulation system and reactor vessel, respectively as shown in Figs. 1 and 2. CASA represents the external surface of a hemispherical vessel submerged in a water pool tank.

The hemispherical heated copper vessel plays a key role in the ERVC test depending on the configuration of the oxide pool and metal layer to bring about the so-called focusing effect expected of a molten pool in the lower head during a severe accident.

The thermal insulation was scaled linearly down by 1/10 as well as 61 in-core instrumentation (ICI) tubes and 4 shear keys. The bottom plate had eight holes for water ingression while allowing for the ICI nozzle to penetrate. The annular and cross-sectional flow areas between the insulation structure and the vessel were geometrically asymmetric for the angular position as presented in Fig. 1. CASA consists of a heated test vessel of 500 mm in diameter, a thermal insulation structure, a water tank, and a condenser. The heated copper vessel simulates a metal layer and an oxide pool in the molten pool using 120 and 165 cartridge heaters, respectively, as depicted in Fig. 2.

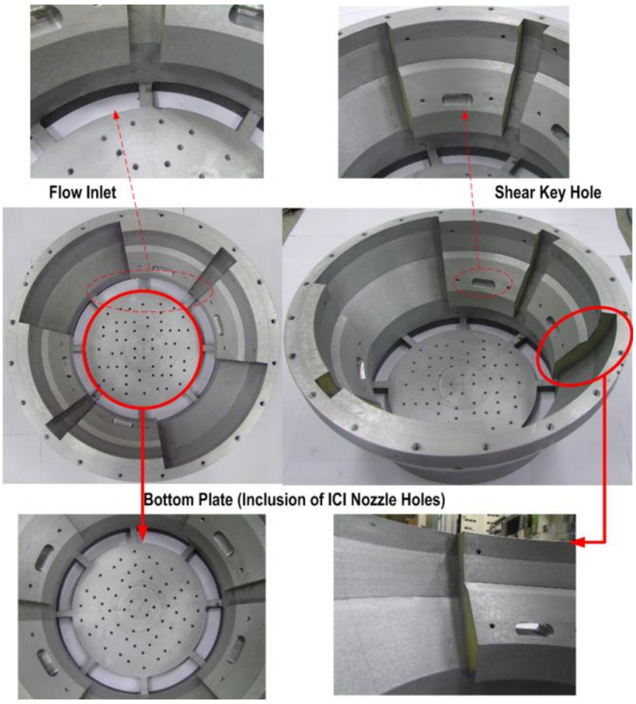

Fig. 1. Thermal insulation structure.

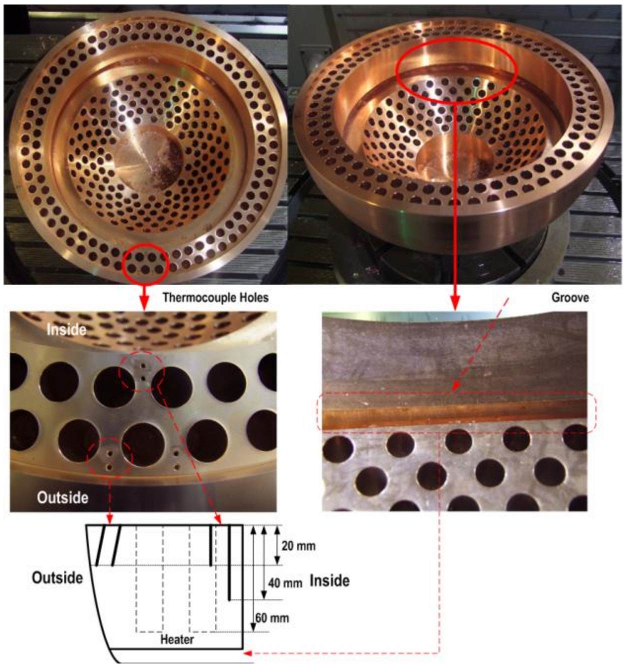

Fig. 2. Hemispherical heated copper vessel.

Figure 3 shows the location for the 26 thermocouples and 4 shear keys.

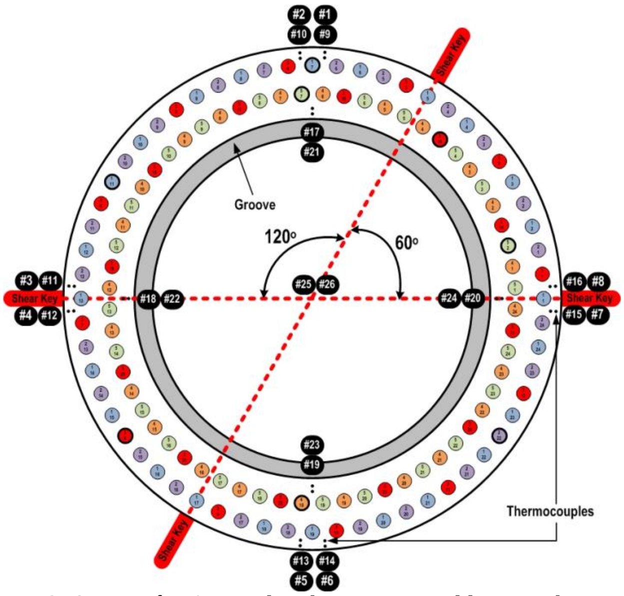

Fig. 3. Arrays of 120 cartridges heaters in metal layer, 4 shear keys and 26 thermocouples in hemispherical copper vessel.

3. Results

The outer surface temperature of the hemispherical copper vessel was maintained at 137°C during a steady state prior to the CHF as shown in Fig. 4. The first spot where the CHF had occurred was not the smaller gap with the shear key but the larger gap without the shear key. The CHF took place initially in the larger gap, and was then spread to the smaller gap. It is thus considered that there is an induced flow in the narrow region with a shear key, which in turn increases the local CHF value. The CHF was thus observed to occur in a 3D fashion on the downward surface of hemispherical copper vessel.

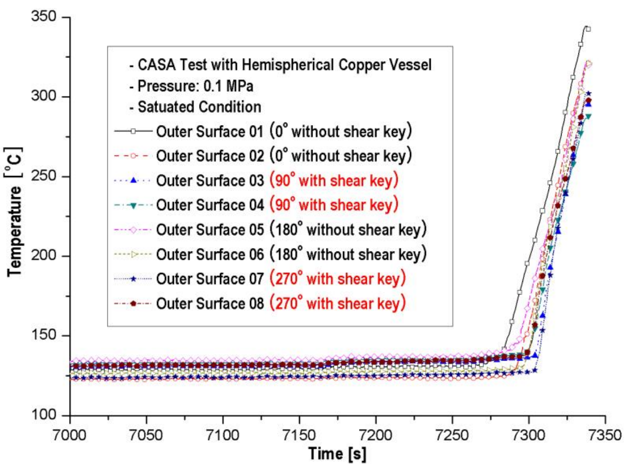

Fig. 4. Temperature history in the vicinity of CHF.

The CHF exceeded 1.5 MW/m^2 in the metal layer as illustrated in Fig. 5. The CHF in the CASA thermal insulator channel was found to be lower than in the streamlined channel of other tests. This is attributed to CASA having the geometrically asymmetric thermal insulation structure, the ICI tubes and shear keys of the APR1400. The CHF tests were performed for saturated boiling under the atmospheric pressure. The inlet subcooling tends to increase the CHF. The CHF will therefore be higher when the APR1400 cavity is flooded with water at room temperature.

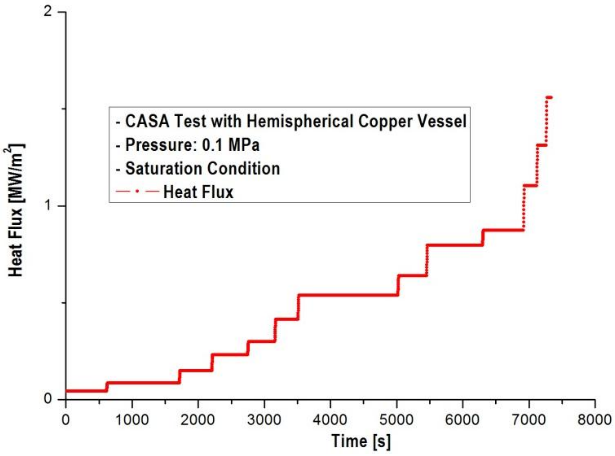

Fig. 5. Heat flux history in outer surface of heated vessel.

Acknowledgments

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